Development and Testing for Physical Security Robots

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ABSTRACT

The Mobile Detection Assessment Response System (MDARS) provides physical security for Department of Defense bases and depots using autonomous unmanned ground vehicles (UGVs) to patrol the site while operating payloads for intruder detection and assessment, barrier assessment, and product assessment. MDARS is in the System Development and Demonstration acquisition phase and is currently undergoing developmental testing including an Early User Appraisal (EUA) at the Hawthorne Army Depot, Nevada - the world's largest army depot.

The Multiple Resource Host Architecture (MRHA) allows the human guard force to command and control several MDARS platforms simultaneously. The MRHA graphically displays video, map, and status for each resource using wireless digital communications for integrated data, video, and audio. Events are prioritized and the user is prompted with audio alerts and text instructions for alarms and warnings. The MRHA also interfaces to remote resources to automate legacy physical devices such as fence gate controls, garage doors, and remote power on/off capability for the MDARS patrol units.

This paper provides an overview and history of the MDARS program and control station software with details on the installation and operation at Hawthorne Army Depot, including discussions on scenarios for EUA excursions. Special attention is given to the MDARS technical development strategy for spiral evolutions.

Keywords: unmanned ground vehicle, UGV, physical security, robotics, autonomous, force protection

1. CONCEPT OF OPERATIONS

1.1 Mobile Detection Assessment Response System (MDARS)

The Mobile Detection Assessment Response System (MDARS) is a joint Army-Navy development effort to provide an automated intrusion detection and inventory assessment capability for use in Department of Defense (DoD) bases and depots, such as materiel storage yards, arsenals, petroleum storage areas, airfields, rail yards, and port facilities. Autonomous MDARS unmanned ground vehicles (UGVs) patrol the site, hosting application payloads for intruder detection and assessment, barrier assessment, and product assessment (see Figure 1). The United States Army Office of the Product Manager, Force Protection Systems (PM-FPS), at Fort Belvoir, VA, is the MDARS program manager. The United States Army Maneuver Support Center (MANSCEN) is the combat developer. SPAWAR Systems Center, San Diego (SSC San Diego) is the technical director and command and control (C2) console software developer. General Dynamics Robotic Systems (GDRS) is the systems integrator and prime contractor.

MDARS meets the Army's requirement for a semi-autonomous mobile capability for patrolling physical security sites. With minimal operator intervention other than system initiation, the patrol unit automatically moves randomly to and throughout designated patrol areas in exterior environments, primarily during non-duty hours. While on random patrol, the patrol unit will conduct surveillance, check for intruders, conduct product inventory, and check the status of facility barriers, such as gate and bunker/container doors. Operator input from the control station will be required only if an intruder is detected or the patrol unit encounters an abnormal situation. If the MDARS system detects an intruder, the video link to the control station is activated and an audio/visual alarm will be annunciated at the control station. This allows security forces to see, hear, and talk to challenge the intruder, as well as send the patrol unit to a location where the intruder has been detected. The patrol unit can also read the status of locks on storage structures (open or closed), and can determine the location of inventory through the use of radio frequency identification (RFID) tags.

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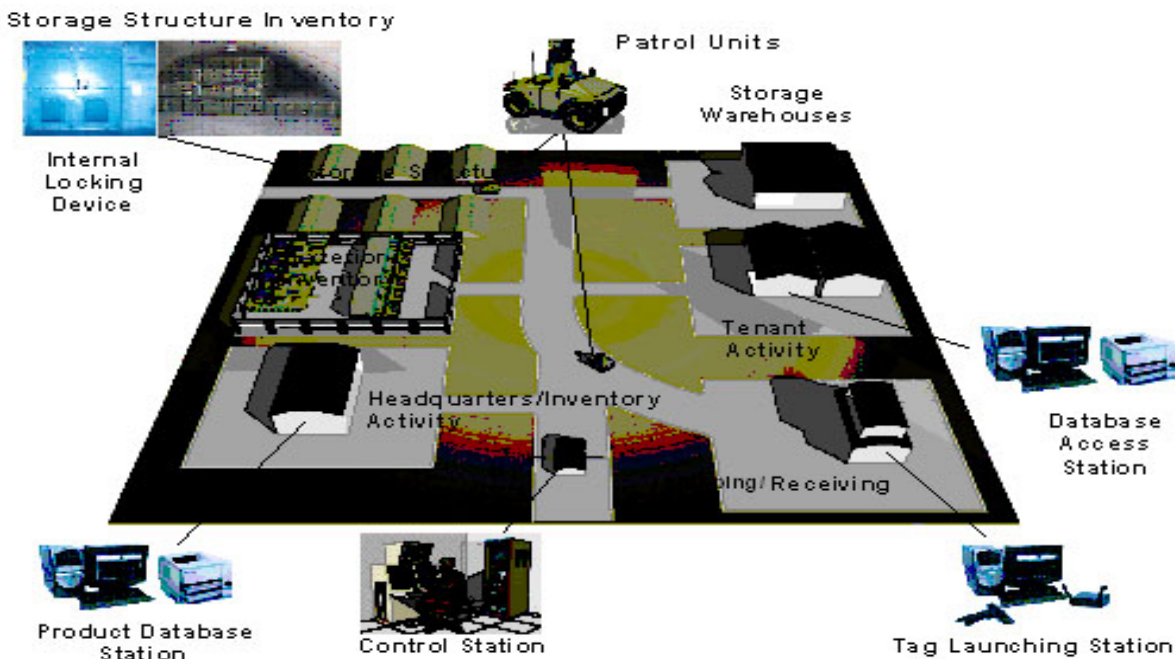
Figure 1. Mobile Detection Assessment Response System Concept of Operations (graphics courtesy of GDRS/PM-FPS)

1.2 Multiple Resource Host Architecture (MRHA)

The MDARS command and control console is based upon the SSC San Diego's Multiple Resource Host Architecture (MRHA), a distributed processing system that allows coordinated control of multiple autonomous resources, including up to 255 unmanned vehicles and/or unmanned sensors over a wireless communications network. The MRHA Operator Station allows the user to control the mobility and payloads of an individual resource (see Figure 2).

Figure 2. Multiple Resource Host Architecture Operator Station

The MRHA graphically displays video, map, and status for each resource. The MRHA Video Server displays video streams simultaneously from up to four different UGVs. The MRHA Supervisor displays information for all resources and allows the user to schedule duty rosters for all resources or to task a specific resource with a pre-scripted mission. Events are prioritized and the user is prompted with audio alerts and text instructions for alarms and warnings. The MRHA also interfaces to remote resources to automate legacy physical devices such as fence gate controls, garage doors, and remote power on/off capability for the MDARS patrol units.

1.3 MDARS Patrol Unit Vehicle (PUV)

The MDARS Patrol Unit Vehicle (PUV) (see Figure 3), developed by General Dynamics Robotics Systems (GDRS), has a suite of sensors and payloads that enable it to be highly autonomous. Under command of the MRHA software, the PUV uses its onboard sensors and application payloads to perform waypoint navigation, detect exceptional events (intruders, unlocked barriers, etc.), and perform barrier and inventory assessments. The PUVs and C2 console communicate over a wireless network based upon IEEE 802.11b technology.
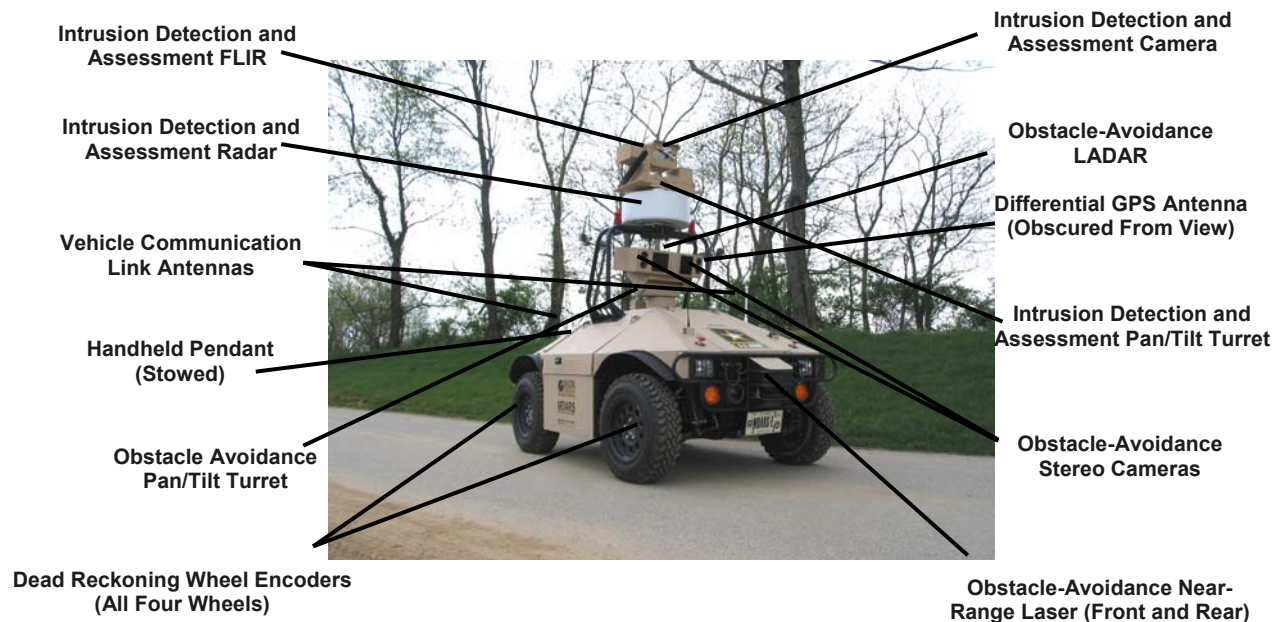

Figure 3. MDARS Patrol Unit Vehicle (graphics courtesy of GDRS/PM-FPS)

The MRHA downloads pre-planned paths to the PUVs, whereupon the onboard autonomous mobility processor navigates using Differential Global Positioning System (DGPS). The Novatel OEM4 Real-Time Kinematics DGPS provides 2 cm accuracy, supplemented by four wheel encoders for dead reckoning and a fiber-optic rate gyro.

The Obstacle Avoidance (OA) Pan/Tilt turret houses the OA Ladar and the OA cameras. The Ladar is the primary OA unit that has 16-line scanning feature to generate a detailed three-dimensional topographic view of the environment. Stereo vision complements the OA map, using two color cameras and two low-light cameras for day and night mission coverage, processed by the Acadia Vision Processor developed by Sarnoff Corporation The final tier of the OA suite are two LMS-221 SICK scanning lasers that provide close-range obstacle detection in front and behind the vehicle.

The PUV employs the Sensor Technology System (STS) radar as the primary Intruder Detection System (IDS), which can detect multiple intruders from a distance of 150 meters. The MRHA and the onboard software can track multiple intruders, marking each with different threat designation signatures from friendly to primary intruder. The PUV then automatically tracks the primary intruder with either the color camera or the uncooled forward-looking infra-red (FLIR) in the IDS turret.

The onboard Mantis Tag reader from RF Code reads RFID tags mounted on externally stored inventory. RFID tags attached to products inside a storage igloo are collected by an internal RFID tag reader in the igloo and recorded on a store-and-forward computer dedicated to the igloo. An interior locking device for the igloo is also connected to the store-and-forward computer to read the lock state (e.g. open, close, or error). A short range transmitter on the outside of the igloo relays the product and barrier assessment data from the store-and-forward computer to the PUV when the PUV approaches the igloo.

2 USER TESTING

2.1 Early User Appraisal (EUA) Objectives

MDARS is in the System Development and Demonstration acquisition phase. The emphasis for MDARS developmental testing is installing and operating the pre-production prototype system at the Hawthorne Army Depot (HWAD) - the world's largest army depot, with 147,000 acres located in west central Nevada (see Figure 4). During testing at Hawthorne, the MDARS system will be operated by the security forces to conduct an Early User Appraisal (EUA) of the installed system with the following goals:

- Determine system utility from the user perspective for the Depot Security Mission at an operation site
- Identify system attributes that could be enhanced to provide better utility
- Identify existing system features that detract from system utility
- Identify any additional missions and tasks to which the system might be applied that have not yet been stated, based on user input after operating the system over time
- Collect trouble/problem data and corresponding corrective action/repair as well as operating runtime
- Collect data from system administrators, electronics and maintenance activities, and logistics on the resources expended in responding to issues

Figure 4. MDARS PUVs on Standby and Patrol at Hawthorne Army Depot, Nevada

2.2 Installation, Deployment, and Operations

For the MDARS developmental and operational testing, four MDARS Patrol Unit Vehicles will patrol during evenings and weekends along predefined paths that include intersections and surveillance nodes. The PUVs will provide security for 270 storage igloos grouped in 15 bunker sites on a section of HWAD (the entire depot has over 2000 storage igloos along 72 miles of base roads). 20 of the storage igloos will be wired for lock and inventory assessment with 200 RFID tags mounted on inventory in multiple bunkers.

The MDARS command and control (C2) console running the MRHA is located in the security office near the legacy annunciator equipment that monitors the fixed sensors on the depot. A secondary MRHA C2 console is in a refurbished maintenance facility, and is used for system training and troubleshooting. The maintenance facility serves multiple purposes, including PUV storage, PUV repairs, training, and operations center for MDARS testing. A fiber-optic

infrastructure connects the MDARS consoles in the security office and maintenance facility to the three relay towers for the wireless network.

The installation process included conducting site surveys, coordinating depot support and resources, setting up the communications network, installing the C2 console and supporting equipment, creating a database of pre-planned paths and nodes, and defining schedules for duty roster and scripts for routine missions.

On site deployment involved extended shakedown testing performed by the system integrator before turning the system over to the users. Throughout the shakedown testing, the targeted users were exposed to the system through demonstrations and extensive training in both a classroom setting and with hands-on involvement. There are five defined training programs to address planned security and inventory management functions:
- System Operators – for users in security office for MDARS C2 software
- Security Response Force – for mobile unit that provides on scene response to exceptional events
- System Administrators – for MDARS C2 software maintenance and administration
- PUV Maintainer – for Preventive Maintenance Checks and Services (PMCS)
- Inventory Management Users and Administrators – for MDARS Product Assessment System (PAS) software

The primary focus of the MDARS EUA is to perform planned security and inventory management functions by the users at an operational site. The plan for the EUA is to exercise the system as intended for physical security during off-duty hours; the EUA will also have controlled experiments to evaluate the system during specific scenarios.

The EUA schedule is divided into ten 12-hour shifts per week – evening shifts everyday at 1730-0530 and day shifts from Friday to Sunday at 0530-1730. The duty roster assigns a pair of MDARS PUVs to each shift – sets of PUVs alternate each shift (e.g. PUVs #1 & #2 patrol on Monday 1730 to Tuesday 0530, PUVs #3 and #4 patrol on Tuesday 1730 to Wednesday 0530, PUVs #1 & #2 operate on the next shift, etc.) Both PUVs in the shift begin their patrol from the maintenance facility, however, each PUV heads in different directions and then operate in separate quadrants during the shift. This allows the system to cover more area during the shift and to deconflict the paths of the PUVs. In a quadrant of bunker clusters, the PUV randomly stops along the path to look for intruders and has programmed stops in front of bunkers to read locks and tags. After a bunker cluster is patrolled, the PUV is randomly assigned a different cluster to monitor. At the end of the shift, the PUV returns to the maintenance facility for PMCS, refueling, and recharging. Each PUV covers almost 100 kilometers per shift!

In normal operating mode, the MDARS system is highly autonomous - the System Operators and Security Response Forces are involved only during exceptional events. To further determine system utility, several scenarios will be executed during the EUA to trigger exceptional events and to demonstrate system capabilities. Events and planned reactions include:
- Walking intruder(s) – PUV alarms, detects, tracks, and challenges
- Fixed IDS alarm – System Operators direct Security Response Forces and PUVs to investigate
- Blocked path – PUV detects obstacle and attempt to navigate past blockade
- Unlocked bunker – PUV alarms and System Operators perform inventory check and visual check with PUV
- Removed inventory from bunker – Report of missing products is available to inventory management
- Moved inventory from bunker – Report of relocated products is available to inventory management

During these scenarios the System Operators will also override the scheduled duty roster for typical operations and assign new tasking to the PUVs including:
- Methodically perform PUV payload operations (e.g. check inventory in every bunker in cluster)
- Dispatch PUV to overwatch positions
  - Base Operations – key intersections on depot
  - Bunker Clusters – visibility to multiple bunkers
  - Material Area – dock loading/unloading

After the EUA, the MDARS prototype system will go through a six-month rework and refurbishment stage to address deficiencies and user-requested changes found during the developmental testing and EUA. Afterwards, the improved

MDARS system will undergo regression testing at HWAD to include data collection for reliability and maintainability before a Milestone C Decision to enter the Production acquisition phase.

2.3 Demonstrated Successes

The MDARS Early User Appraisal is currently underway at Hawthorne Army Depot. Throughout the prototype design, development, and preliminary testing, the system has been demonstrated to meet many of the operational requirements.

2.3.1 Semi-Autonomous Navigation

MDARS PUVs drive, navigate, and avoid obstacles autonomously, in a consistent, safe, and predictable manner with response speed (32 kilometers per hour) exceeding requirement by more than 100%. The system has been operating successfully on paved, poorly paved and unpaved roads at HWAD for several months. A full tank of fuel provides over 16 hours of mobile operations. Minimal operator assistance is required to execute missions. Users are provided the necessary controls and functionality to operate the system, and perform the necessary missions. Vehicles perform unassisted intersection and traffic detection/response, and unassisted U-turns. Vehicles behave reasonably in and around the bunker areas, on roads, and in the presence of normal traffic. Inclines of up to 45% have been negotiated.

2.3.2 Command and Control

MDARS performs all semi-autonomous modes of operation properly, including randomized patrols, methodical patrols, directed control/sends and manual/telereflexive control. Control is predictable, reliable and easy to use. The system provides shift-level and task-level automation through the use of "duty rosters" and a "mission" hierarchy. PUVs can be quickly and easily directed/re-directed according to situational needs, and PUVs respond with maximum autonomy and minimal operator intervention. All routine tasks are performed without the need for frequent or continuous monitoring by the user. Communication ranges greater than 3000 meters from a relay/repeater have been demonstrated. Uninterruptible power supply (UPS) provide backup for 11 hours of control station usage during power outage.

2.3.3 Application Payloads

Intruder Detection and Assessment System components meet or exceed the performance requirements, with measured detection and assessment rates between 95 to 99% in the range of 100 – 200 meters from the PUV. The interface is easy to use and provides the user adequate controls and feedback for the intruder assessment tasks. Automatic intruder detection and tracking functions perform very well. Audio assessment and two-way communication function properly.

The Barrier Assessment System integrates with the government furnished Interior Locking Devices (ILDs), and functions according to specification. Lock breaches are detected and reported accurately and reliably. The system behaves properly when a breach is detected, and the user is notified immediately.

The Inventory Assessment System operates accurately and reliably, and meets the performance requirements: 99.9% of tags are successfully read – for internal storage, up to 200 meters from bunker; up to 50 meters from exterior tag. Product assessment data is read by the PUV and passed on to the product database. A variety of reports are available to alert the user of any abnormal conditions, including missing items, moved items, etc.

2.3.4 Training/Usability

The training program has been very successful, with documentation and manuals complete and accurate. On-site personnel have been trained and are able to effectively operate the system.

2.3.5 Maintainability

The system is maintainable. Most of the recent support and repair tasks have been performed by on-site maintenance personnel. The system provides an extensive set of built-in-tests and diagnostic functions to detect and report any subsystem and/or component failures. Diagnostic data is available locally through the pendant, and remotely at the control station. It includes guided, manual PMCS instructions to walk the maintainer through a complete set of pre- and post-mission checkout tasks. The system is capable of executing various automatic recovery functions, and degraded-mode operation as necessary. The vehicle pendant provides the ability to exercise, check out, diagnose and troubleshoot

virtually every subsystem through the on-board software. The PUV is easily recoverable using standard towing equipment.

2.3.6 Environmental

Most of the subsystems meet or exceed the environmental requirements. Considerable run time has been accumulated recently at HWAD. The electronic systems meet the shock and vibration requirements, and most of them meet the environmental requirements. Specific, isolated electrical components or sensors have been identified which do not meet the high temperature (chamber) conditions. For each of these, wider temperature range alternatives are available and can be incorporated. Improvements have been made in the temperature performance of the automotive system, through both hardware and operational changes. We have accumulated hundreds of miles of operation since the pilot test, at higher speeds (well in excess of the required speed) without any over temperature faults.

3   SPIRAL DEVELOPMENT

Ongoing efforts to extend MDARS for integrated force protection missions involve spiral development with focus on interoperability and collaboration.

3.1 Joint Architecture for Unmanned Systems (JAUS)

SSC San Diego is a contributor to the JAUS development of message sets for internal and external communications for unmanned vehicles. In FY-03, the JAUS Operator Control Unit (OCU) and Payload Committee planned a sequence of experiments to demonstrate and expand the level of interoperability between OCUs and unmanned vehicles. SSC San Diego hosted and participated in the first JAUS OCU and Payloads Committee experiment where nine organizations implemented a JAUS message set for teleoperation on six different unmanned systems – each consisting of an OCU and an unmanned ground vehicle (Fig. 8). Each OCU was then able to monitor the status of every UGV and each OCU could take individual control and teleoperate any of the unmanned vehicles. SSC San Diego and the JAUS Working Group continue to expand the experimentation domain to assess JAUS message sets required for payloads and missions.
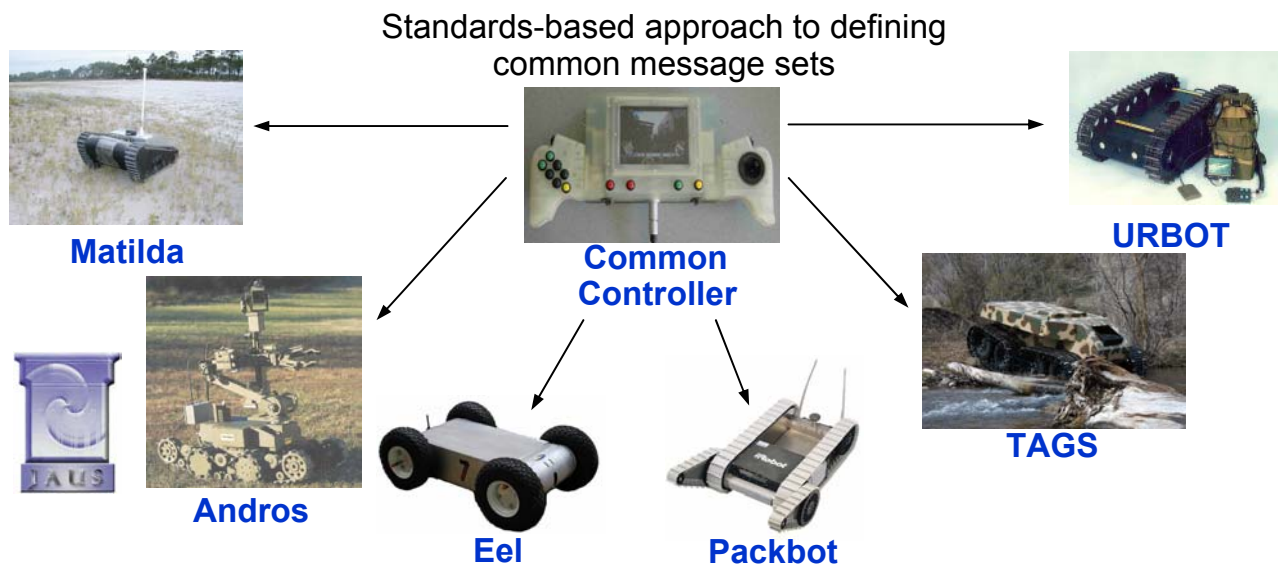

Figure 5. Joint Architecture for Unmanned Systems (JAUS) Operator Control Unit (OCU) and Payload Committee Experiment

3.2 Remote Detection Challenge and Response (REDCAR)

The Air Force Remote Detection Challenge and Response (REDCAR) initiative is a System of Systems approach of Surveillance, Engagement, and Reconnaissance platforms (see Figure 6) to address the unmanned component for the Air Force Integrated Base Defense (IBD). Deploying REDCAR robotics platforms, including the MDARS UGV, the SCOUT designed by the AFRL Robotics Group, and a small scale platform such as Matilda or Packbot, around an air

base or installation would help to delay or mitigate an aggressor's progress, thereby allowing security forces to mount an effective and timely counter. REDCAR uses JAUS messages for the REDCAR C2 software to operate the UGVs.

Figure 6. Remote Detection Challenge and Response (REDCAR) Surveillance, Engagement, and Small Reconnaissance Platforms

3.3 Family of Integrated Rapid Response Equipment (FIRRE)

The Family of Integrated Rapid Response Equipment (FIRRE) deploys UGVs and UGS for force protection (see Figure 7).

Figure 7. Family of Integrated Rapid Response Equipment (FIRRE) TAGS, MDARS, and BAIS Components

FIRRE is an advanced technology demonstration program intended to develop a family of affordable, scalable, modular, and logistically supportable unmanned systems to meet urgent operational force protection needs and requirements worldwide. The near-term goal is to integrate the MDARS UGV, Tactical Amphibious Ground System (TAGS) UGV, Battlefield Anti-Intrusion System (BAIS) UGS, and AN/PPS-5D/E Ground Surveillance Radars to provide force protection for forward deployed units (see Figure 7).

US Army PM-FPS is the FIRRE Program Manager. US Army Product Manager Robotic and Unmanned Sensors (PM-RUS) is selecting and acquiring the sensors. Northrop Grumman Remotec is the FIRRE Systems Integrator and manufacturer of the TAGS robotic vehicle. GDRS is the manufacturer of MDARS UGV and developer of the Autonomous Navigation System (ANS). SSC San Diego is the FIRRE Technical Director and C2 Console Developer.

3.4 Composeable FORCEnet Network Intelligence Reconnaissance Surveillance (CFn NISR)

Composeable FORCEnet Network Intelligence Reconnaissance Surveillance (CFn NISR) is a SSC San Diego proof-of-concept effort to extend the command and control for unmanned systems to the FORCEnet arena (see Figure 8) for the interface to the DoD Global Information Grid (GIG). By providing a web-accessible interface to robotic resources, CFn NISR implements a network-centric capability that is core to the FORCEnet vision. CFn NISR is derived from the MDARS Command and Control software and is comprised of a Robot Server and Java-based Multi-robot Operator Control Unit (JMOCU). The Robot Server manages robotic resources on the network and publishes robotic information. JMOCU provides the user interface to the Robot Server for real-time video stream, robot status, and waypoint navigation control. It can be run as a stand alone application or a web accessible applet from a standard browser.

Figure 8. Composeable FORCEnet Network Intelligence Surveillance Reconnaissance Operator Control Unit

4   SUMMARY

The Mobile Detection Assessment Response System provides physical security for Department of Defense bases and depots using autonomous unmanned ground vehicles to patrol the site while operating payloads for intruder detection and assessment, barrier assessment, and product assessment. MDARS is in the System Development and Demonstration acquisition phase and is currently undergoing developmental testing including an Early User Appraisal (EUA) at the Hawthorne Army Depot, Nevada - the world's largest army depot. The goal of the MDARS EUA is to perform planned security and inventory management functions by the users at an operational site. Throughout the prototype design, development, and preliminary testing, the system has been demonstrated to meet many of the operational requirements. MDARS Spiral Development is extending the mission to integrated force protection with focus on interoperability and collaboration with unmanned systems.

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